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PHASE COMPENSATION FOR HIGH POWER LASERS
USING REFRACTING GAS PRISMS

FINAL SCIENTIFIC REPORT
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(May 1, 1977 to October 31, 1978)

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I. Introduction

Active optics refers to optical components whose characteristics are controlled during actual operation, in order to modify wavefronts. While the concept of active optics has been known for some time, only recently is the technology emerging that will effect the design of high performance laser systems.[1,2]

Laser beams propagating through the atmosphere are subject to considerable phase distortion due to variations of the air density. The beams emitted by high-power lasers can also be distorted due to density variations inside the laser cavity. One of the main applications of active optics is the compensation of these wavefront distortions in order to enhance the intensity of a laser beam on a distant target. It is possible to correct to a substantial degree for these phase distortions by passing the beam in question through an array of elements which impose controlled phase variations which compensate for the distortion. This involves the measurement and control of wavefronts in real time in order to concentrate the energy on to a detector or target. Usually this is done by contouring mirrors in the transmitting optics and is referred to as COAT (coherent adaptive optical technique).[1] Good improvements have been achieved with low-power visible laser propagation in the atmosphere. Unfortunately, correction for high-power infrared lasers is considerably more difficult because of the need for larger amplitude mirror deflections and heating of the active mirror surfaces.

A new method of phase compensation using the refractive properties of gas jets is being investigated at the University of Washington, as an alternative method for phase front control. Gases of different optical properties (index of refraction) with sufficient optical depth are placed in the path of the laser so that passage through the gas elements produces phase shifts in the beam itself. Actively changing the gas index of refraction using flow will permit the control necessary to achieve phase compensation. The geometry required to bring about

localized phase compensation in the laser beam is possible by using independent jets of gas each with its own dither and feedback circuiting as is done with conventional COAT technology. By replacing the solid array elements by jets of gas of varying refractive index, the power handling capacity of the COAT system can be raised to very high levels (up to $\sim 10^{9}$ w/cm^{2}) while maintaining a frequency response in the kilocycle range. This is the essence of the fluid COAT idea. With free jets of gas performing the phase-shifting, one of the prime concerns is the amount of beam degradation produced by the inevitable turbulent shear layers. The experimental investigation of this beam degradation mechanism constitutes much of the first effort in the project. During this contract period we have constructed a number of different devices for testing the concept using low-power visible lasers as probes. In particular, a Mach Zhender interferometer for measuring the phase distortion introduced by the free jets in the near-field has been constructed. The necessary flow apparatus to provide free jets with cross sections on the order of one centimeter was completed. However, variable control of the refractive index has not yet been attempted. Lastly, a telescope apparatus has been built so that the far-field pattern of the laser beam can be observed within distances on the optics test table.

Preliminary investigations of the interaction of a He-Ne laser beam with the jets has been carried out. The first preliminary work was the investigation of the shear layers on a single rectangular M=2 free jet. The jet size is scaled to the He-Ne wavelength used in the investigation so as to produce comparable phase shifts to those which would be involved in a 10.6μ, 10 cm aperture system. The Reynolds number is not properly simulated in this experiment, but may be in future work. A number of jets of N_2, Ar, He and a He-Ar mixture were investigated. Near-field interferograms and far-field power-in-the-bucket measurements were taken using a CW He-Ne laser. The near-field inteferograms show excellent

fringe quality within the jet, and phase shifts of $\pm 2\lambda$, depending on the operating gas. The far-field power-in-the-bucket measurements show that the reduction in the peak beam power caused by the jet is in the range of 5-10%, as expected, and depends on the operating gas. Scaling the results to infrared wavelengths suggests that the jets and their shear layers do not degrade the far-field intensity of a laser beam by more than five to ten percent. The details of this work are described in the thesis entitled "Degradation of a Laser Beam through a Supersonic Free Jet." A copy of the title page is appendixed with this report. A copy of the thesis was forwarded with the previous annual report.

II. The Concept

Simple Examples

An example illustration of one aspect of the concept is sketched in Fig. 1. Fig. 1(a) shows 3 views of an array of 5 rectangular phase-shifting elements assembled to form a square aperture through which a laser beam is passed. Each phase-shifting element can be independently controlled to produce any desired phase-shift (up to a certain maximum value). The phase-shifting elements are gas jets with variable refractive indices. This would allow much higher power laser beams to be controlled than could be handled by solid phase-shifting elements. Fig. 1(b) shows the array in operation with the phase shifting elements producing linearly decreasing phase delays from element 1 to element 5. The approximate result of operating the array in this manner would be to slew the output beam as shown. If the laser beam passes through two such arrays at right angles to each other, altitude and azimuth can be slewed. The discussion illustrates one particular type of laser beam control, chosen as an introductory example because of its simplicity. However, the same techniques can be applied to adjust the phase fronts of a laser beam.

Another possible configuration for a gasdynamic COAT system is sketched in Fig. 2, which shows an eight-element radial flow configuration. The required

phase shifts may be produced by varying the refractive indices in the jets produced by the nozzles. Depending on the application, the index of refraction of the jets can be changed by mixing either different gases or similar gases at different temperatures. A possible valving system for accomplishing these changes is shown in Fig. 3(a). The use of fluidic technology may offer an alternative to the mechanical valve shown in the figure. A possible fluidic flow control configuration is sketched in Fig. 3(b).

The Crossed Array

A 6-element fluid COAT system might employ crossed parallel-flow gasdynamic phase shifting arrays; a possible configuration is sketched in Fig. 4. It should be pointed out that in such a simple configuration which involves effectively nine prisms, only six of which are independent, arranging more elements differently can increase the flexibility. In actual practice enough elements will be required so that an effective COAT system is achieved. The optimum arrangement is being worked on and preliminary calculations are detailed in Section IV.

Mass Flow Requirement

An estimate of the mass flow required of a phase-shifting array can be made if it is assumed that moderate pressure (115 psia) supplies of hot and cold air are used to operate the phase shifters. The stagnation temperature of the cold gas is assumed to be 70° F (530°R) and that of the hot gas 600° F (1060°R). We consider the two extreme positions of the slide valve shown in Fig. 3(a). In one case we have a jet composed entirely of hot gases and in the other a jet composed entirely of cold gases. In either case, it is assumed that the nozzles expand the gas to sea level atmospheric pressure, 14.17 psia, which corresponds to a jet Mach number of 2. To calculate the maximum phase shift which can be produced by changing from a hot jet to a cold jet, we must calculate the maximum change in n, the index of refraction.

$\Delta n = \frac{\beta}{\rho_s}(\rho_c - \rho_h)$ where β = Gladstone-Dale constant and the subscripts c, h and s refer to cold, hot and standard respectively. Substituting the calculated values of $\frac{\rho}{\rho_s}$ and the known constant, β, yields

$$\Delta n(\max) = 0.000244.$$

Consider operation with a CO_2 laser with $\lambda = 10.6\ \mu = 1.06 \times 10^{-3}$ m. For effective operation, a phase shift capability of $\pm 2\pi$ (720°) must be realized.[1,2] The phase change available across a slab of material (the jet thickness) of thickness t and with refractive index change $\Delta n(\max)$ is given by

$$\Delta\phi = \frac{2\pi\ \Delta n(\max)\ t}{\lambda} \qquad (1)$$

where $\Delta\phi$ = phase change available

λ = wavelength of radiation.

Substituting the calculated value of $\Delta n(\max)$, the wavelength λ, of the radiation used and the required phase change, $\Delta\phi$ yields a slab thickness

$$t = 8.5 \text{ cm}.$$

If a 10 cm x 10 cm laser aperture is to be controlled, the total jet cross section is estimated as 16 x 10 = 160 cm^2. From the above numbers we estimate a mass requirement of approximately 15 lb/sec of air for a single optical pass. If the rays can be reflected back through the jet in order to increase the optical path, the flow rate is reduced by two.

In summary we note that the mass flux, m, is

$$\dot{m} \alpha \ \frac{\rho}{\Delta\rho}\left(\frac{d\lambda U}{\beta}\right)\frac{1}{N}$$

where U = flow velocity

d = jet dimension associated with the window dimension

ρ = static density

Δ = maximum density differences

N = number of optical passes

This formula shows that a sizeable reduction in mass flow occurs at the shorter wavelength such as associated with the DF & CO laser system.

Frequency Response Characteristics of the Concept.

We note that the phase modulation frequency, f, for gas optics is $f = K\frac{U}{d}$, where K = constant depending on the dither arrangement and frequencies. This limit is based on the time it takes a fluid element to cross the aperture and has no relation to how the jet is controlled. If the aperture size is decreased by a factor of 10, (to a 1 cm x 1 cm aperture), the frequency response will increase by a factor of 10 if the jet velocity remains unchanged, or can be kept at the same value by reducing the jet velocities by a factor of 10. Intermediate operating conditions are also possible. In either case reduced dimension gives improved frequency response as well as much lower mass flow requirements. If the aperture size is reduced by a factor of 10 the mass flow requirements would be reduced by a factor of 10 if the jet velocity was kept unchanged (to achieve the higher frequency response) or by a factor of 100 if the jet velocity was reduced to maintain the same frequency response. Again an intermediate operating condition between the two extremes might be used.

For a 10 x 10 cm aperture system, the maximum usable frequency was estimated above a 2.5 KHZ. This is not, however, the maximum frequency response of the overall system. Rather, it is the frequency at which the highest effective modulation may be placed. Depending on the type feedback system used, this reduces the freouency of overall response considerably.

III. Experimental Progress

a) Gas Handling Systems

Gas handling systems for N_2 and He have been built and tested. A third gas handling system for Ar is under construction. These systems include storage reservoirs, pump and regulating and metering equipment necessary for the gas jets.

b) Optical System

An optical system for the desired experiments has been developed and

tested. This system is set up at present as a Mach-Zhender interferometer using a He-Ne laser. Fig. 5 shows the interferometer system without the nozzle under test in position. The interferometer has been used to measure the near-field phase distortion of the laser beam on passing through the gas jets of a simulated system. The system, to date, has given excellent interferograms of single 6 mm N_2 and He jets. Typical interferograms are shown in Fig. 6. Shadowgraphs have also been obtained by a simple modification of the interferometer. If desired, Schlieren photographs could also be obtained. The optical system has been designed so a Q-switched ruby laser can be substituted for the He-Ne laser, allowing photographs to be obtained with nanosecond exposure, effectively stopping the jet flow. The 1/125 second (typical) exposures used to date with the He-Ne laser do not, of course, stop the flow, and therefore photographs are time-averaged over the passage of turbulence in the jet. Fringes in interferograms will, for example, tend to be flurred by this effect. The complete details of this system are given in an M.S. thesis entitled "Degradation of a Laser Beam through a Supersonic Free Jet." A copy of the title page is appendixed to this report.

A Q-switched ruby laser (15 mJ, 40 ns pulses) has been built and tested. The laser has a coherence length of greater than eight feet and a focused spot size within a factor of 2 of the theoretical value. This laser has been built to be shared between the fluid COAT project and a second project. It has not been used for measurements at this point.

c) Nozzles

A single 6 mm nozzle has been built and preliminary measurements have been taken with N_2 and He jets. The interferograms of Fig. 6 were taken with this nozzle. A triple 6 mm nozzle producing a 2-element "COAT array" has been designed, but not yet built. One of the elements in this nozzle is designed to produce a variable phase shift using a mechanical control system.

IV. Preliminary Optimization Calculations

Basic Notations on a Phase Shifter

Ideally, one would like to correct the phase front distribution in a continuous manner and at infinite frequency response. The basic concept, however, uses a finite number of descrete, and not necessarily independent, free jets with a finite frequency response. Thus, there will be differences between the real system and the ideal system. It is important to minimize and control this type of error. This section describes some basic ideas and results along these lines.

As previously described, the idea is to modify the phase distribution across a laser beam by passing it through a collection of gas jets. The gas jets serve as "phase retardation slabs," and the phase change, $\Delta\phi$, across a uniform slab with thickness t is given by equation (1) where Δn is the change of the index of refraction of the slab with respect to some reference. Hence $\Delta\phi$ can be controlled by changing t or Δn.

As a first example, consider the arrangement shown in Fig. 7, where there are two sets of jets (in different planes): M jets in the χ-direction and N jets in the y-direction.

Let us denote the phase changes induced by the χ-jets by χ_i, and the phase changes of y-jets by y_i. Since the phase changes are additive, we have

$$\chi_i + y_j = \phi'_{ij} \qquad \begin{matrix} i = 1,2,\dots,M \\ j = 1,2,\dots,N \end{matrix} \qquad (2)$$

where ϕ'_{ij} are the total phase change induced by the jets in the rectangle defined by the intersection of the jets χ_i and y_j.

Our control problem is the following: Given the desired phase changes ϕ_{ij}, what are the "best" χ_i and y_j to do the job? The errors for each desired phase are

$$x_i + y_j - \phi_{ij} = \varepsilon_{ij} \tag{3}$$

If we define the total error as

$$R \equiv \sum_{j=1}^{N} \sum_{i=1}^{M} \varepsilon_{ij}^2 = \sum_j \sum_i (x_i + y_j - \phi_{ij})^2 \tag{4}$$

and the jet "strengths" are chosen to minimize R, i.e.,

$$\frac{\partial R}{\partial x_i} = 2 \sum_{j=1}^{N} (x_i + y_j - \phi_{ij}) = 0 \tag{5}$$

and

$$\frac{\partial R}{2y_j} = 2 \sum_{i=1}^{M} (x_i + y_j - \phi_{ij}) = 0 \tag{6}$$

The last two equations can be rewritten as:

$$Nx_i + \sum_{j=1}^{N} y_j - \sum_{j=1}^{N} \phi_{ij} = 0 \quad ,i = 1,2,\ldots,M \tag{7}$$

$$My_j + \sum_{i=1}^{M} x_i - \sum_{i=1}^{M} \phi_{ij} = 0 \quad ,j = 1,2,\ldots,N \tag{8}$$

The M + N equations (7) and (8) for the M + N unknowns, $_i$ and y_j, have a non-unique solution, since if $_i$ and y_j is a solution, so is $_i + C$, $y_j - C$, where

C is an arbitrary constant. To make the solution unique we can impose another condition. For example, we can minimize the function

$$\sum_{i=1}^{M} \chi_i^2 + \sum_{j=1}^{N} y_j^2 = f(\chi_i, y_j) \tag{9}$$

subject to the constraint that Eqs. (7) and (8) are satisfied.

We solve this problem by the method of Lagrange multipliers. Define

$$S \equiv \sum_i \chi_i^2 + \sum_j y_j^2 + \sum_i \lambda_i \{N\chi_i + \sum_j y_j - \sum_j \phi_{ij}\} + \sum_j \mu_j \{My_j + \sum_i \chi_i - \sum_i \phi_{ij}\} \tag{10}$$

where λ_i and μ_j are Lagrange multipliers. Hence,

$$\frac{\partial S}{\partial \chi_i} = 2\chi_i + N\lambda_i + \sum_{j=1}^{N} \mu_j = 0, \qquad i = 1,2,\ldots.M \tag{11}$$

$$\frac{\partial S}{\partial y_j} = 2y_j + \sum_{i=1}^{M} \lambda_i + M\mu_j = 0 \qquad j = 1,2,\ldots,N \tag{12}$$

Our problem now is to solve Eqs. (7, 8, 11, 12) for χ_i, y_j, λ_i and μ_j. We proceed as follows:

First we sum Eqs. (11) and (12) to get

$$\sum_i \chi_i = -\frac{1}{2}(N\sum_i \lambda_i + M\sum_j \mu_j) \tag{13}$$

$$\sum_j y_j = -\frac{1}{2}\left(M\sum_j \mu_j + N\sum_i \lambda_i\right) \tag{14}$$

Comparing (13) and (14) we note that

$$\sum_{i=1}^{M} x_i = \sum_{j=1}^{N} y_j \equiv Z \tag{15}$$

However, from the summation of our original equation, Eq. (3), over all i and j we have

$$N\sum_i x_i + M\sum_j y_j = \sum_j\sum_i \phi_{ij} \equiv Q \tag{16}$$

since $\sum_j\sum_i \varepsilon_{ij} = 0.$

By substituting Eq. (15) into (16) we get

$$Z = \frac{Q}{M+N} \tag{17}$$

Introducing Eqs. (17) and (15) into Eqs. (5) and (6) we obtain the desired solution

$$x_i = \frac{1}{N}\left[\sum_{j=1}^{N} \phi_{ij} - \frac{\sum_{j=1}^{N}\sum_{i=1}^{M} \phi_{ij}}{M+N}\right], \quad i = 1,2,\ldots,M \tag{18}$$

$$y_j = \frac{1}{M}\left[\sum_{i=1}^{M} \phi_{ij} - \frac{\sum_{j=1}^{N}\sum_{i=1}^{M} \phi_{ij}}{M+N}\right], \quad j = 1,2,\ldots,N \tag{19}$$

As an example, assume that we have two jets in χ direction and two jets in y direction. Hence, from Eqs. (18, 19) we have

$$x_1 = \frac{1}{2}(\phi_{11} + \phi_{12} - Z) \qquad x_2 = \frac{1}{2}(\phi_{21} + \phi_{22} - Z)$$

$$y_1 = \frac{1}{2}(\phi_{11} + \phi_{21} - Z) \qquad y_2 = \frac{1}{2}(\phi_{12} + \phi_{22} - Z)$$

where

$$Z = \frac{1}{4}(\phi_{11} + \phi_{12} + \phi_{21} + \phi_{22})$$

The errors, defined by Eq. (3), are in this case:

$$\varepsilon_{11} = x_1 + y_1 - \phi_{11} = -\frac{\Delta}{4}$$

where

$$\Delta \equiv \phi_{11} + \phi_{22} - \phi_{12} - \phi_{21}.$$

Similarly one finds

$$\varepsilon_{12} = \frac{\Delta}{4}, \quad \varepsilon_{22} = -\frac{\Delta}{4}, \quad \varepsilon_{21} = \frac{\Delta}{4}.$$

Comments: (1) Note that there is no guarantee that the x_i and y_j computed by Eqs. (18) and (19) come out to be positive. If some of the jet "strengths" are negative, one can "shift" the solution by adding a constant C to all jets in one direction and subtracting it from the other direction, so that no jet strength is negative.

(2) The errors defined in Eqs. (3) and (4) are not necessarily the best criterion, since what one is really interested in is to maximize the light intensity. The light intensity grows when the phase is made more uniform at all apertures; however, it is not clear that Eqs. (3) and (4) give the best criterion.

(3) The function defined by Eq. (9) is not truly the one which one wishes to minimize. Rather, one would like to minimize the mass flow in the jets which is proportional to

$$\sum_i |x_i| + \sum_j |y_j| .$$

However, this latter problem is more difficult to handle analytically and has not yet been carried out.

Advanced Phase Shifters

Instead of the configuration described in Fig. 1, one can consider various other possibilities. For example, consider Fig. 8 where the beam area is covered by four sets, each consisting of two jets. Here we number all the jets "strengths" (i.e., the phase change that they introduce) by x_j, j = 1,2,...,8, and the desired total phase changes in the beam by ϕ_i, i = 1,2,....,16.

As before, we have to solve

a linear problem

$$\sum_{j=1}^{8} A_{ij}\, x_j = \phi_i \qquad i = 1,2,\ldots.,16 \tag{20}$$

where the matrix A_{ij} is the 16 x 8 matrix:

$$\begin{matrix}
1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\
1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\
1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
1 & 0 & 1 & 0 & 1 & 0 & 0 & 1 \\
0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 \\
0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\
0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\
1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\
1 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\
1 & 0 & 0 & 1 & 0 & 1 & 0 & 0
\end{matrix}$$

Again we can define the error

$$A\underset{\sim}{\chi} - \underset{\sim}{\phi} = \underset{\sim}{\varepsilon} \tag{21}$$

where we now use a vector notation. As before we try to minimize

$$R = \underset{\sim}{\varepsilon} \cdot \underset{\sim}{\varepsilon} = (A\underset{\sim}{x} - \underset{\sim}{\phi}) \cdot (A\underset{\sim}{x} - \underset{\sim}{\phi}) \tag{22}$$

where the dot denotes the scalar product. Now,

$$\frac{\partial R}{\partial \underset{\sim}{x}} = 2A^T (A\underset{\sim}{x} - \underset{\sim}{\phi}) = 0,$$

where A^T is the transpose of A.

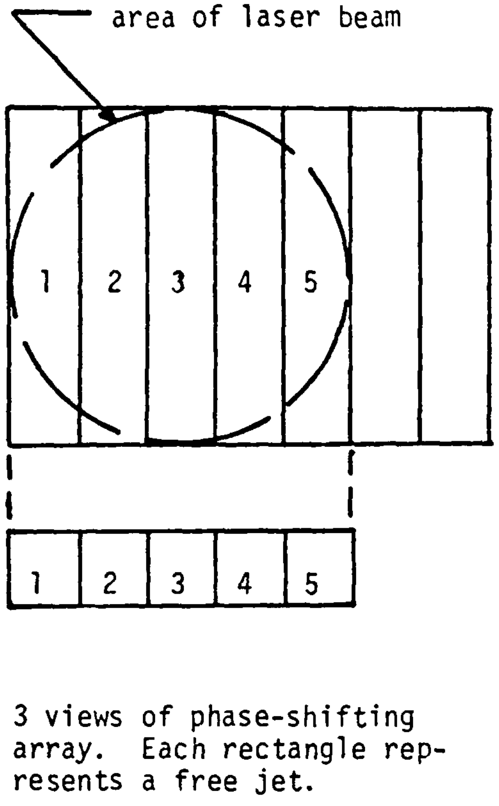
Hence, the solution is:

$$\underset{\sim}{x} = (A^T A)^{-1} A^T \underset{\sim}{\phi} \tag{23}$$

Note that if $(A^T A)$ is a nonsingular matrix, Eq. (23) determines the jet strengths uniquely. In our previous example described in Fig. 7, the matrix $A^T A$ was singular and we had the freedom to minimize the function defined in Eq. (9). Further work has not been done on the geometry indicated by Fig. 8.

REFERENCES

1. J. Hardy, Proc. IEEE 66, 651 (1978).
2. J.E. Pearson, et al., Appl. Optics 14, 611 (1976).



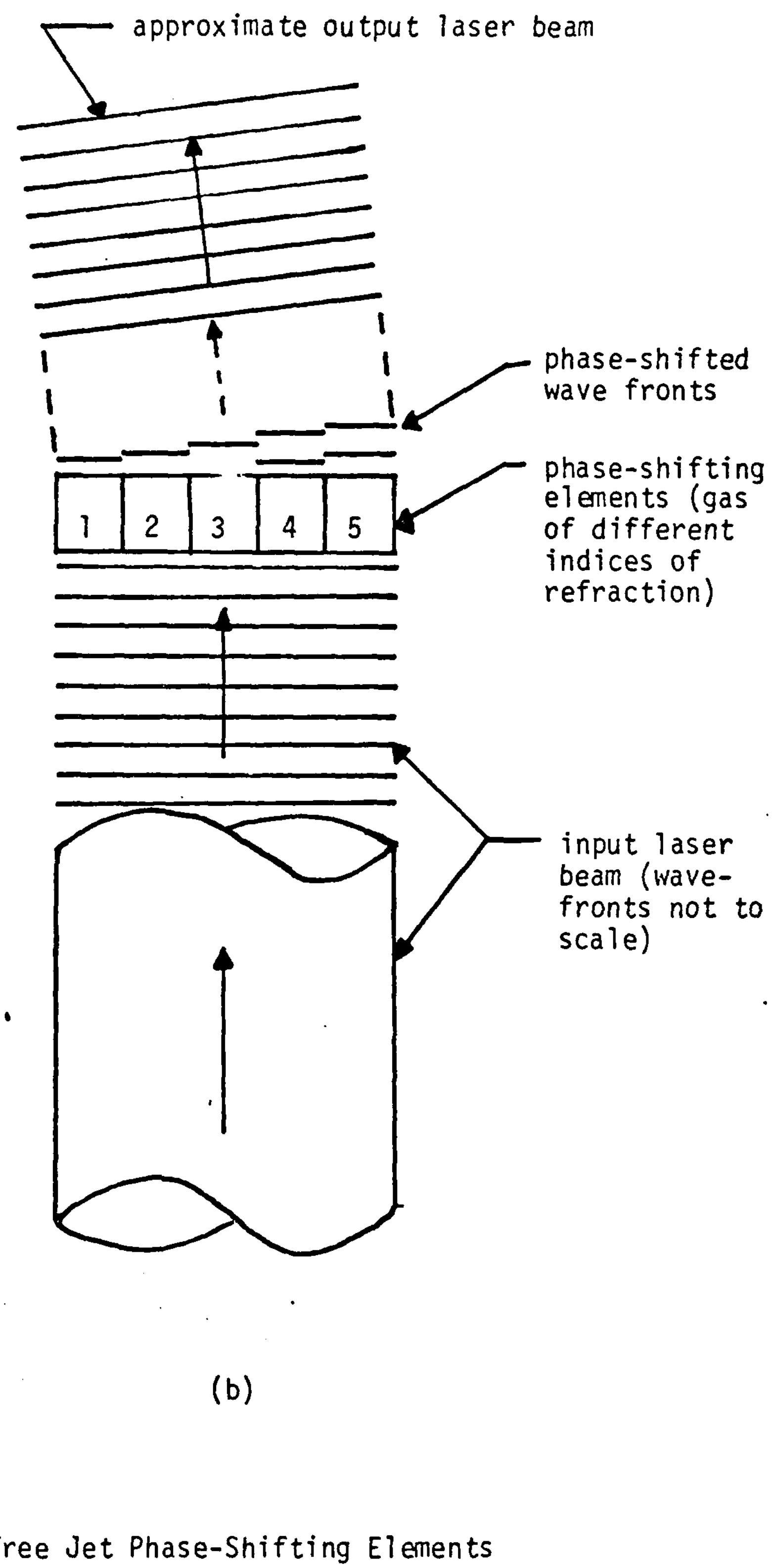


Fig. 1. Beam Slewing Using Free Jet Phase-Shifting Elements

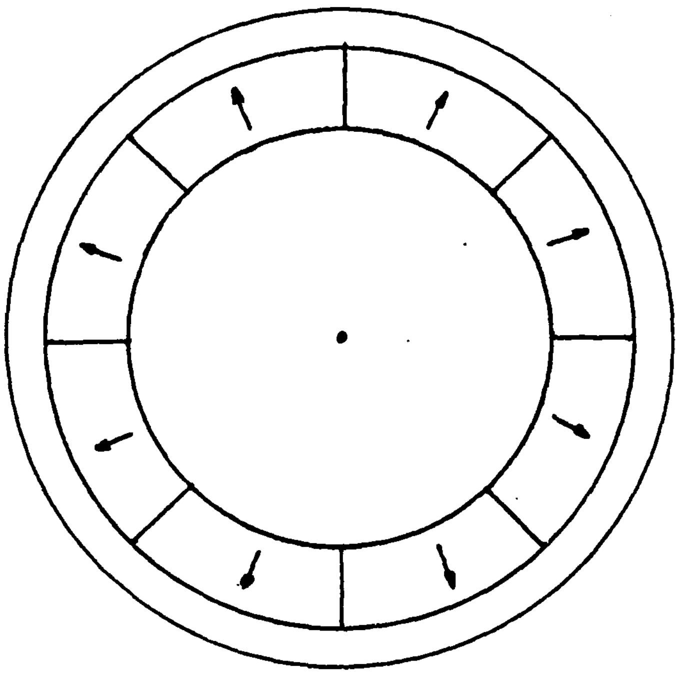


Fig. 2. A Possible Configuration for Gasdynamic Phase-Shifting Arrays. This configuration may be useful with an edge-coupled laser producing a beam of annular cross-section. The laser beam would be perpendicular paper and the arrows represent the flow direction of the free jet.

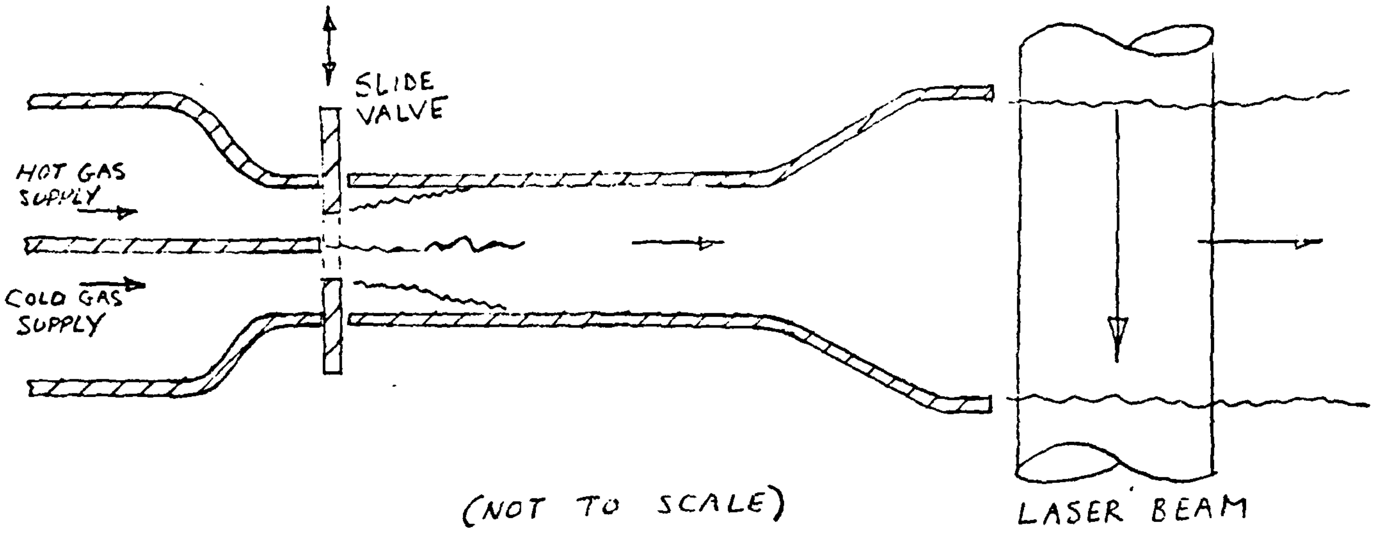


FIG. 3(a) POSSIBLE CONFIGURATION FOR MODULATING VALVE

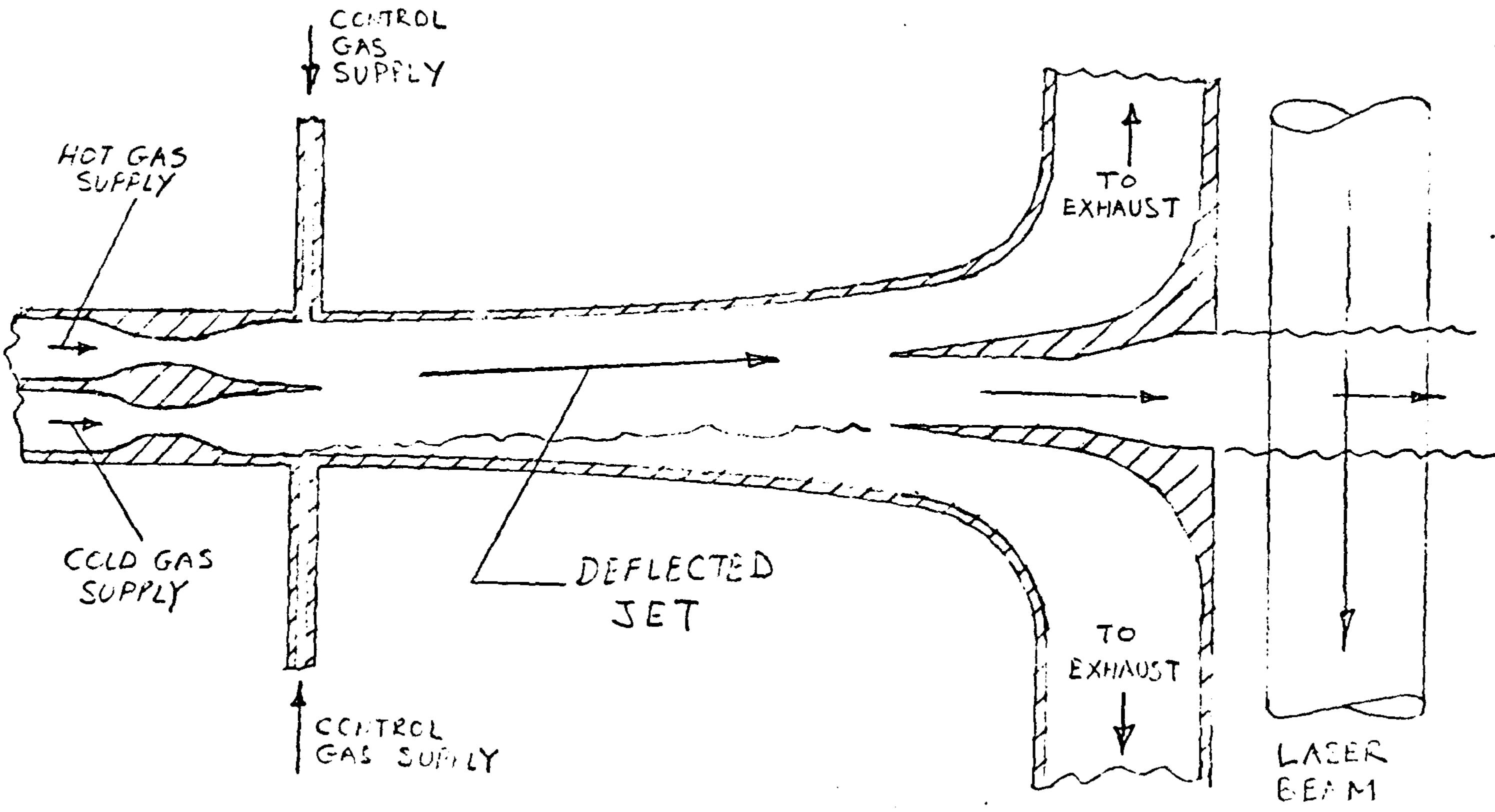


FIG. 3(b) POSSIBLE FLUIDIC FLOW CONTROL SYSTEM

Fig. 3

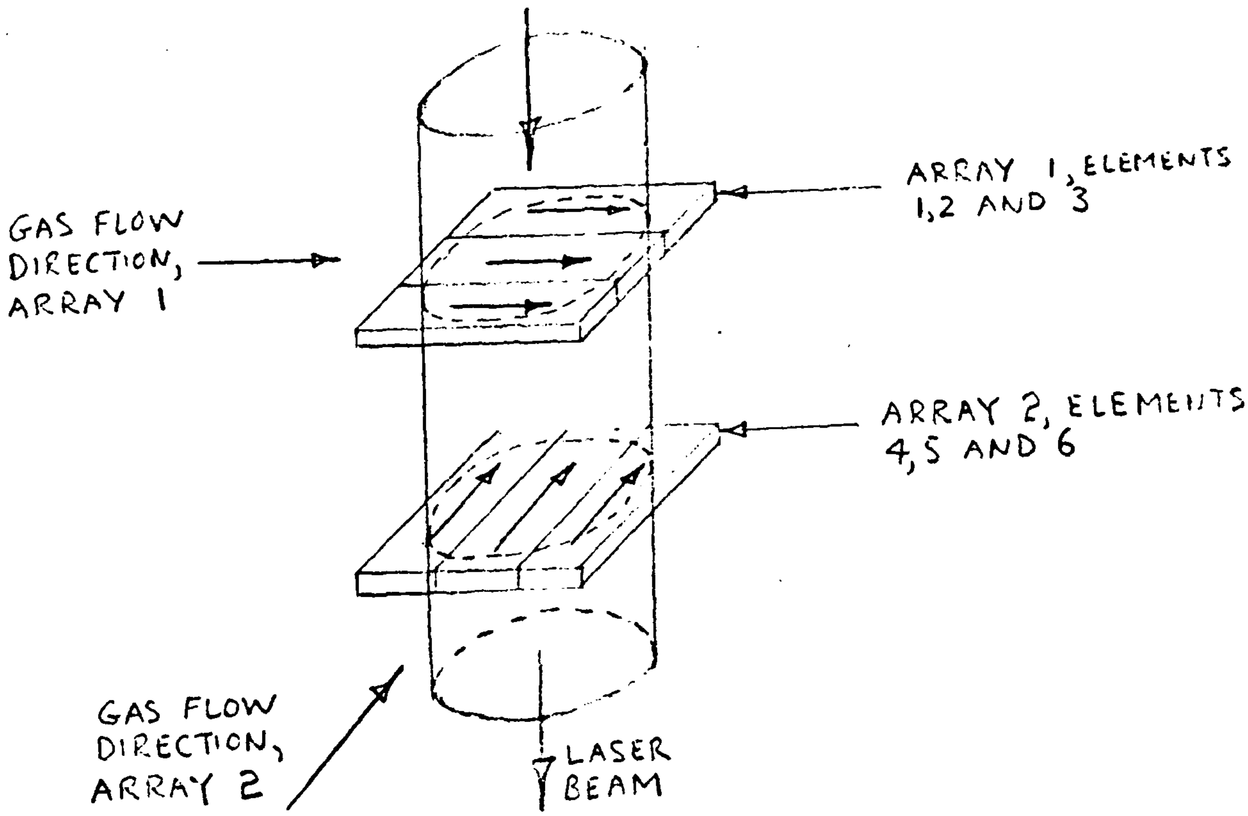


Fig. 4. Possible Configuration for a 6-Element COAT System

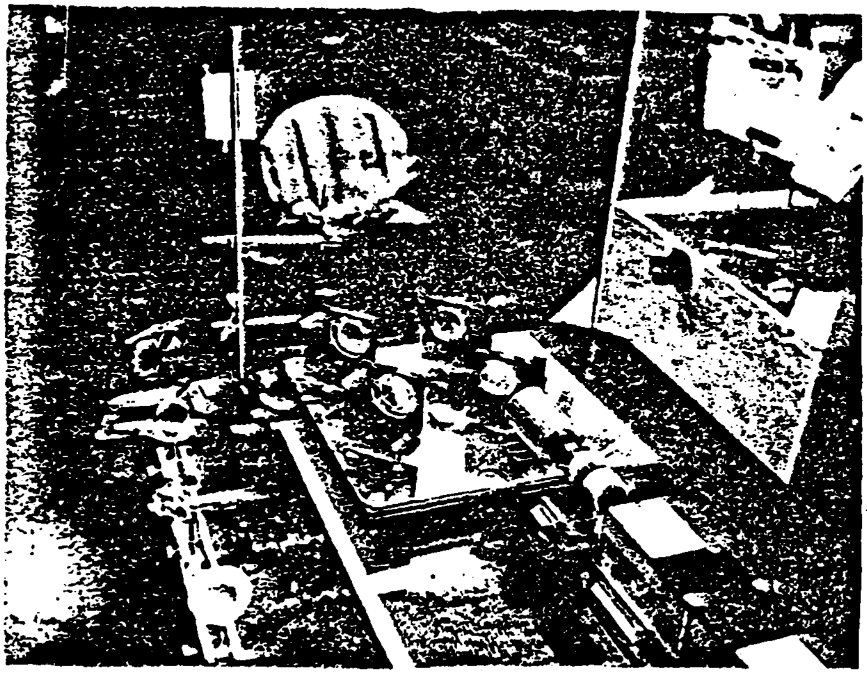
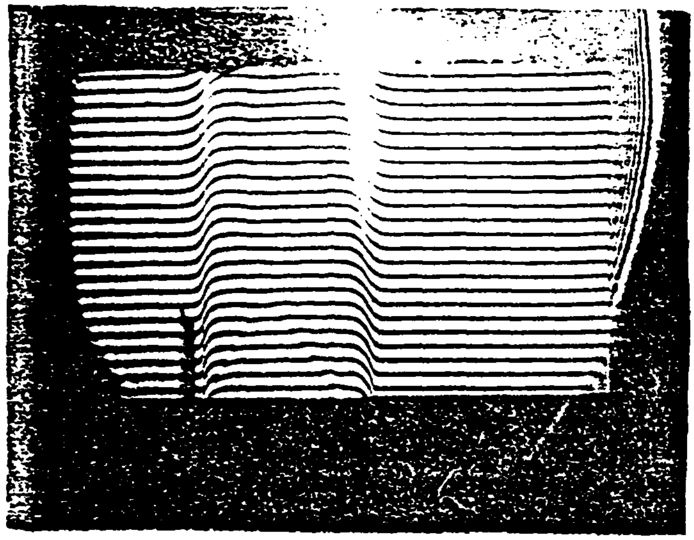
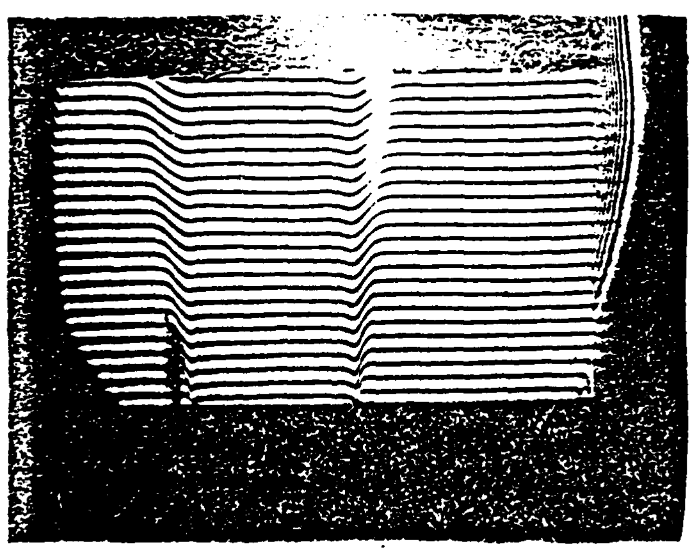


Fig. 5. Laser Interferometer
(Nozzle not in Position)



(a) Nitrogen



(b) Helium

Fig. 6. Interferograms of Jets from
6 mm Single Nozzle

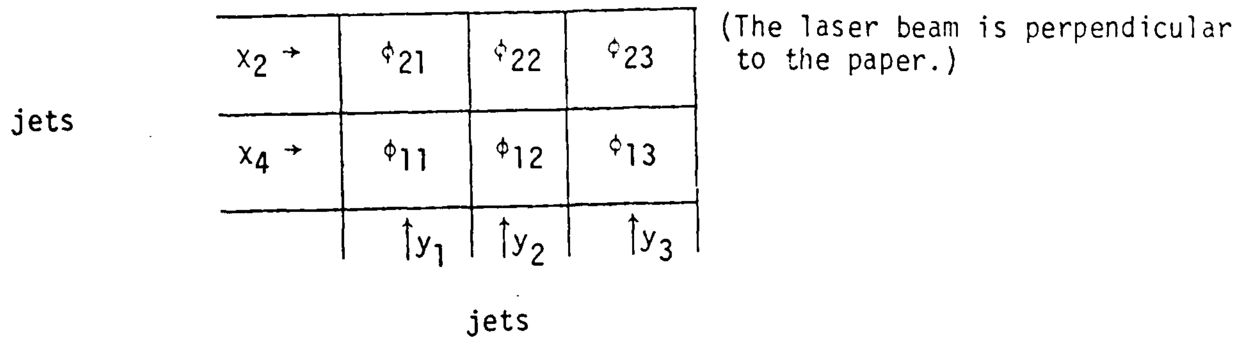


Fig. 7. A Six Jet System

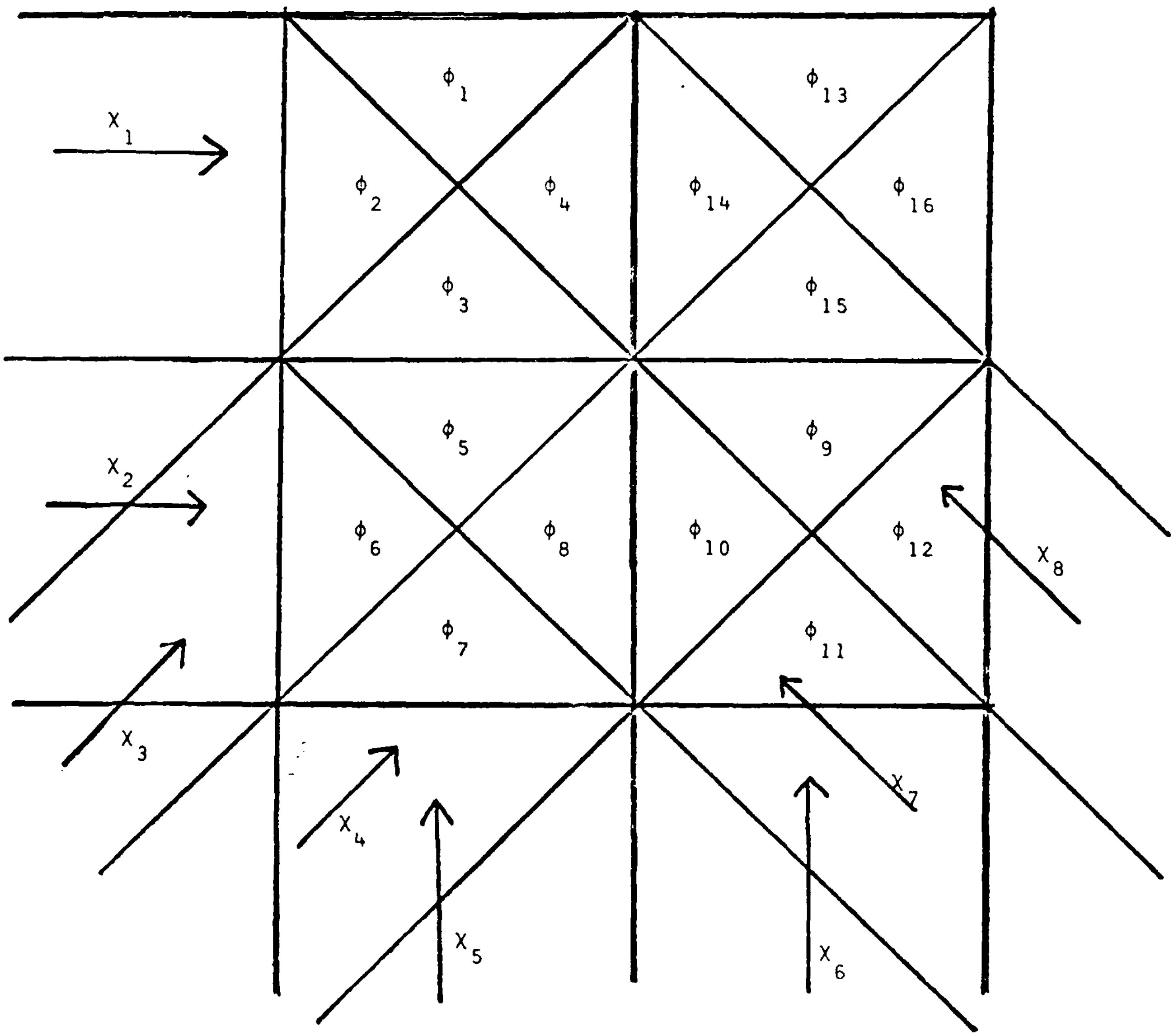


Fig. 8. A 16 Jet Phase Shifter System

APPENDIX

DEGRADATION OF A LASER BEAM THROUGH A SUPERSONIC FREE JET

by

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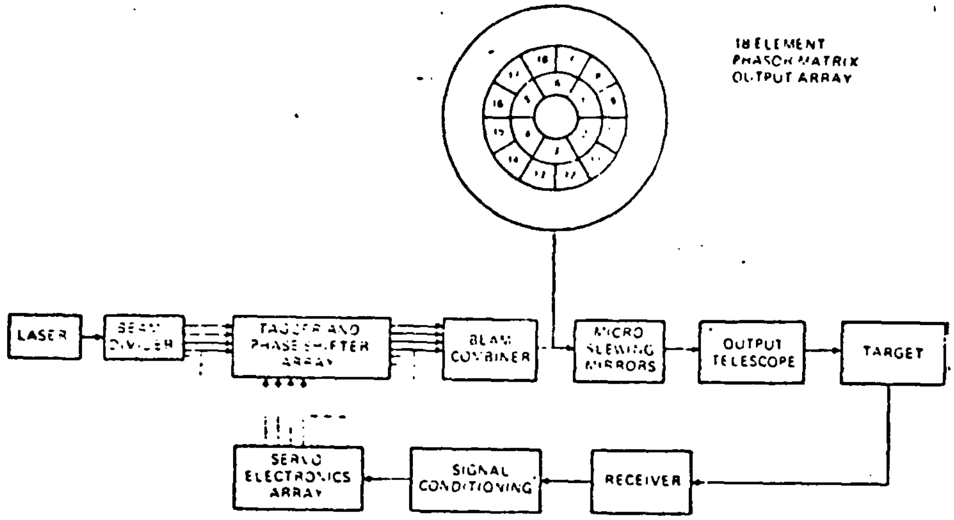
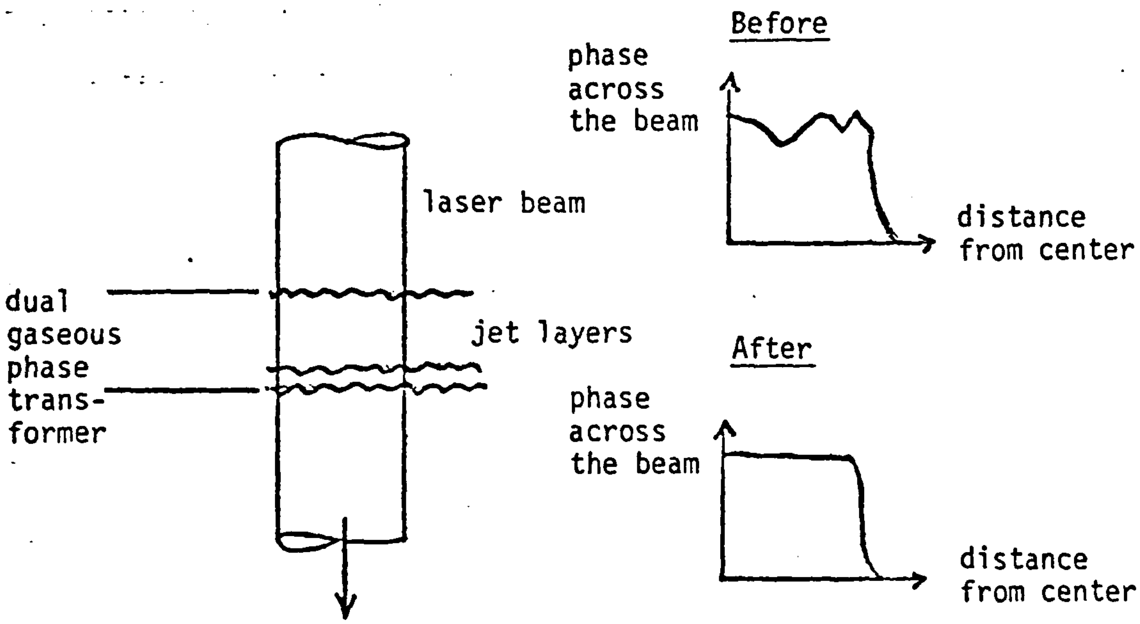
I. INTRODUCTION

High power lasers can suffer beam distortion as a result of interaction of electromagnetic energy with the guiding media and the inner structure of source resonators. Atmospheric media can also distort the beam through linear (turbulence) and nonlinear (self-focussing, thermal blooming) effects. One may describe these distortions in terms of a phase generator which operates on the laser beam and distorts its phase front. In a reverse sense, a phase generator may be also used to correct influences by proper phase modulation across the beam. This can be achieved in principle either by programmed modulation or feedback controlled modulation. The programmed modulation depends in its algorithm on the actual perturbation.[7]

A feedback controlled technique (also known by "coat"-coherent optical adaptive techniques) is shown schematically in Fig. 1a.[9] The feedback setup or phasor-matrix division may be different from those that are shown here, but the basic idea is a general one. Feedback is guided by the desire to maximize irradiance on target. The phase modulation is achieved by vibrating mirrors (dithers) which may reach their limitations at high power and frequency. The limits are connected with heat overloading (up to 1% of laser power) as well as large moments of inertia introduced by the mirrors. Mirror heat-loading in a high power laser is close in a sense to a problem faced by optical windows which serve between 10^2 W/cm^2 to 10^3 W/cm^2.[10]



a) Multidither COAT system Block Diagram.[5]



b) Dual Gaseous Phase Transformer[11]

FIG. 1

An alternative method of gaseous optics as a phase modulator was proposed in Ref. 11. In this idea independent jets of gas with variable optical density may be combined to shift the phase across the laser beam. The optical density change may be achieved by parallel jets of hot and cold gases (two extremes of index of refraction) in a supersonic nozzle (Fig. 1b). The mixture with certain phase shift ability intercepts the crossing beam on the exit of the nozzle.

In this thesis the effect of such jets on laser beam which propagates through them was experimentally investigated. The investigation was made in the near-field of an expanded low power laser beam using a Mach-Zehnder interferometer. A semiquantitative discussion of the free jet as a phase transformer is contained in this thesis. Some properties of the far field pattern of the "dephased" beam are analyzed and a preliminary estimate is made for the "extinction coefficient"[15] of the jet. Some work concerning coherent features of the probe laser is presented in Appendix I.